SOUND&VIBRATION

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New Acoustical Testing Laboratory at NASA

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The NASA John H. Glenn Research Center at Lewis Field has designed and constructed an Acoustical Testing Laboratory (ATL) to support low-noise design of microgravity space flight hardware. This new laboratory provides acoustic emissions testing and noise control services for a variety of customers, particularly for microgravity space flight hardware that must meet International Space Station (ISS) limits on noise emissions.[1]

The ATL provides a comprehensive array of acoustical testing services, including sound power level testing per ANSI S12.34 and ANSI S12.35.[2,3] A multichannel PC-based acoustical data acquisition system allows simultaneous acquisition and real-time analysis of signals to facilitate the identification of equipment noise sources and transmission paths. Although the ATL functions as a design verification facility by producing data to document requirements compliance, it was constructed primarily to provide an in-house laboratory environment where noise control design strategies are actively pursued and integrated into the overall design of flight hardware, early in the life of each project.

Acoustical Testing Laboratory Design Goals. Science experiment payloads that will reside on the International Space Station are subject to acoustic noise emission requirements, which have been imposed by ISS to support hearing conservation, speech communication and safety goals as well as to prevent noise-induced vibrations that could adversely impact microgravity research data. These requirements include meeting an NC-like maximum sound pressure level criterion spectrum for acoustic emissions (the exact spectrum depends on the nature of the payload and its intended operational characteristics) as well as conducting sound power level testing in accordance with any of several published standards.

Although ISS policies require the above testing for final verification and compliance purposes, the primary motivation for the design and construction of the Acoustical Testing Laboratory at Glenn Research Center was the need for an accessible, secure and flight-hardware-compatible acoustical testing environment that would virtually ensure compliance by facilitating the successful implementation of low-noise payload design strategies.

The ATL was designed as a reconfigurable hemi/anechoic chamber in order to be able to meet either ANSI S12.34 or ANSI S12.35 (or both) for typical experiment payloads up to a full rack in size (approximately 3-ft by 3-ft by 6-ft high). Vibration isolation and very low background and self-noise levels were dictated by the need to acquire accurate and repeatable acoustic emission measurements on the least-noise-producing component of a payload, typically a small fan.

Most larger payloads, especially full racks that serve as permanent on-orbit test beds for a succession of payloads by providing common utilities and service connections, usually require the operation of test support equipment in order to generate noise under ground-based laboratory conditions. It is necessary to prevent noise generated by this support equipment, which can include high-noise items such chillers, pumps and power supplies, from contaminating acoustical measurements of the experiment itself. As a result, the support equipment must be located in a remote, noise-attenuating enclosure with the capability of running service hoses and cables between the test support enclosure and test chamber to permit operation and control of the test article without any attendant acoustic leaks between the two rooms.

Facility Description. The Acoustical Testing Laboratory consists of a test chamber with 27-ft by 23-ft by 20-ft high outside dimensions (21-ft by 17-ft by 17-ft high interior working dimensions) and separate sound-attenuating test support enclosure with outside dimensions of 23-ft by 11-ft by 12-ft high. The ATL is located, along with two other engineering verification facilities, inside a preengineered host building with dimensions of 50-ft by 150-ft by 35-ft high. The host building provides the ATL with a conditioned exterior environment, overhead crane support and utility services such as chilled water and shop (compressed) air (see Figures 1 and 2).

Test Chamber Design. NASA established an in-house design team to develop the technical requirements for a laboratory design that would meet the specialized demands of microgravity space flight hardware. In particular, the laboratory was configured to be able to accommodate the Fluids and Combustion Facility, a three-rack microgravity research facility being developed for the International Space Station by the NASA Glenn Research Center's Microgravity Sciences Division under contract to Federal Data Corporation. The NASA team worked closely with Jeff Morse, Vice President of Engineering at Eckel Industries, Inc., who coordinated the efforts of

Figure 1. Access door frame being installed. The test chamber complex was assembled from prefabricated modular components.

Figure 2. Finished chamber complex within high-bay test facility with crane and floor access services.

Figure 3. Test specimen access opening showing split door sections and wedge/floor modules on movable platforms.

Eckel's own design team.

Constraints on the available space in the host building dictated a smaller chamber than would have allowed full anechoic testing of the largest test articles per ANSI S12.35. Therefore, the capability of configuring the chamber as either anechoic or hemi-anechoic was incorporated into the design to ensure that even the largest test articles would fall within the applicability of either ANSI S12.34 or ANSI S12.35. This is accomplished with removable floor wedges mounted on rolling carts. The chamber design was tailored to support reconfigurability by employing horizontally-split doors, shown in Figure 3, and a set of personnel access steps built into one of the floor wedge carts. Removable modular expanded-metal grating sections attached to each floor wedge cart provide a walking surface above the wedge tips.

The main test room consists of a 23 ft wide by 27 ft long by 20 ft high convertible hemi-anechoic chamber with a separate control room test support enclosure. Absorptive 34 in. Eckel metallic wedges (EMWs) in the test chamber provide an anechoic environment down to 100 Hz. The EMW anechoic wedge design incorporates high transparency perforated 22 gage perforated metal facing with a 53% open area. The wedges have a fiberglass core and acoustically transparent fabric layer between the perforated facing and fiberglass core for positive fiber containment. The chamber's EMW lining is modular with two 34 in. peaks per wedge unit with a 2 ft by 2 ft base.

An above-grade spring-isolated floor system affords vibration isolation above 3 Hz for test articles with a maximum weight of 5000 lbs (see Figures 4 and 5). Snubbers below the 6-in. concrete slab allow an 8000-lb forklift truck to safely maneuver test articles into position.

Low background noise levels required for accurate acoustic measurements are afforded by prefabricated 4-in. thick wall panels with an internal septum, which provide noise reduction, rated at STC 54, between the host space and the test chamber. A silenced two-speed stand-alone ventilation system with 50% efficiency filtering provides conditioned air from the host space.

To permit equipment access, the test chamber has one set of 9-ft by 10-ft high double doors, shown in Figure 6, as well as a removable 8-ft by 8-ft panel in the ceiling that may be lifted by crane. A personnel door functions as an emergency egress exit. When the chamber is configured in the full anechoic mode, a set of portable steps is positioned on the exterior of the chamber during laboratory operations to permit entrance/egress between the walking surface above the floor wedges (approximately 46-in high) and grade level in the host building.

A "very early" smoke detection system continuously samples air in the test chamber and the test support enclosure and notifies a central lab-wide monitoring/dispatch station of any threshold exceedances.

Figure 4. Test chamber seismic base with rebar and vibration isolator forms in place ready for concrete pour.

Figure 5. Vibration isolator elements and leveling devices being installed.

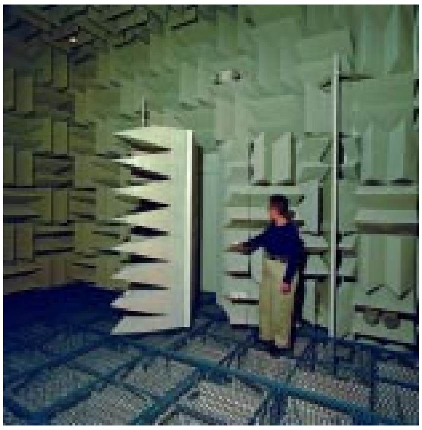

Figure 6. Inside view of test chamber configured for anechoic measurements with test specimen access door wedge sections open.

Figure 7. Test support enclosure showing movable equipment and storage modules.

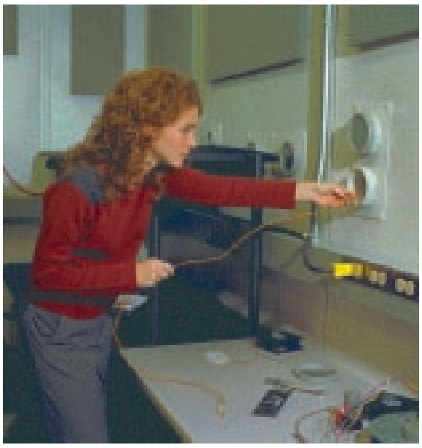

Figure 8. Test specimen service utilities are provided to the main test chamber interior by means of access sleeves with silencer plugs.

Test Support Enclosure Design. The test chamber and adjacent test support enclosure are physically and acoustically separate structures located on either side of a 4-in. air space filled with fiberglass insulation. For most test programs, the test support enclosure functions as a control room and houses acoustic data acquisition and customer test control equipment. The test support enclosure is also a pre-fabricated room with 4-in. thick wall and ceiling panels rated at STC 49. Silenced (rated at NC 25) and filtered (30% efficiency) two-speed ventilation and absorptive interior wall/ceiling panel surfaces provide the office-like environment appropriate for most operations. The ventilation system is separate from both the host building system and the stand-alone system that serves the test chamber.

For test programs where the test article requires remotely-located test support equipment whose noise emissions could contaminate the acoustic signals being measured in the test chamber, the test support enclosure shown in Figure 7 functions as a noise control enclosure. In this case, the acoustical data acquisition and customer test control equipment and functions are relocated to the hallway outside the test support enclosure by means of rolling equipment carts and movable modular furnishings. Electrical receptacles on the exterior walls of the chamber and test support enclosure facilitate easy recon-figuration of the test control and data acquisition setup. The floor of the test support enclosure is located at grade, enabling equipment to be moved in and out easily through a set of 8-ft by 10-ft high double doors.

Test support equipment located in the enclosure is powered by 120 VAC or 208 V 3-phase electrical service supplied to the control room and, in turn, provides services to the test article in the chamber via temporary customer-supplied hoses, cables, and tubing that pass through silenced utility sleeves in the walls of the two rooms as shown in Figure 8. Utility sleeves in the other walls allow phone, Ethernet, shop air and water services to be temporarily supplied to the test sup-

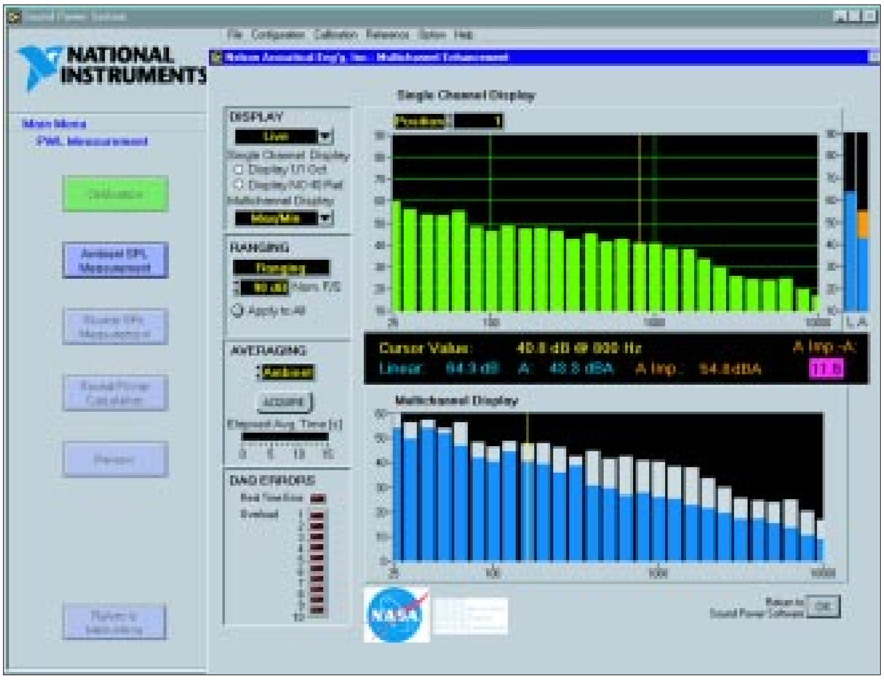

Figure 9. Multi-Channel Enhancement user interface with Min/Max display.

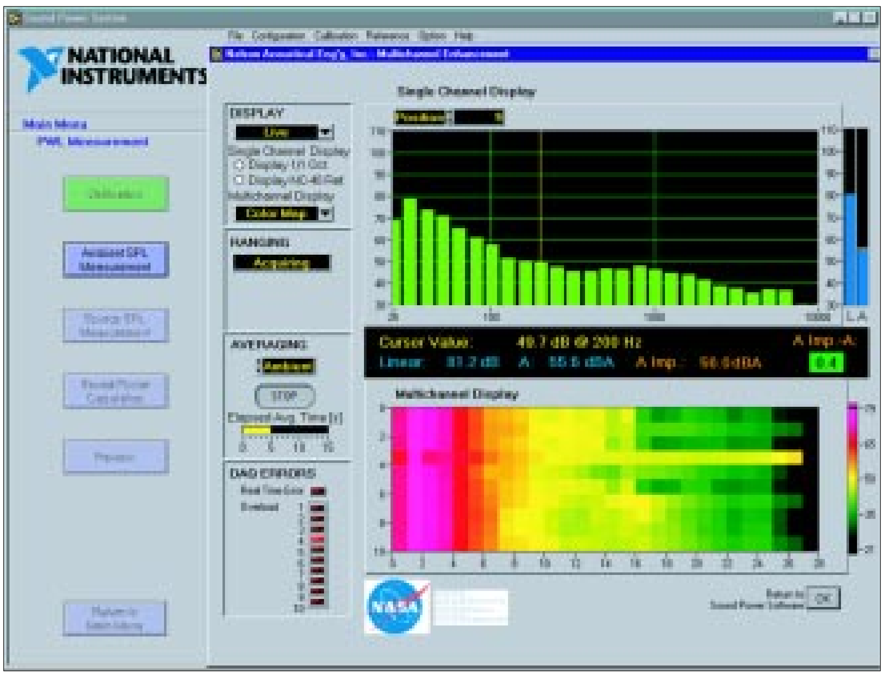

Figure 10. Multi-Channel Enhancement user interface with color chart.

port enclosure from the host building and also allow these services as well as data/control functions to be routed, when required, to the alternate test control location in the adjacent hallway. Video and intercom systems facilitate remote test operation as well as communication between the chamber and other locations during setup and testing.

Personnel traffic between the test chamber and test support enclosure must pass through a series of two aligned doors, one in each of the rooms. A set of steps recessed into the floor wedge cart located immediately inside the chamber provides a means of navigating the change in elevation between the floor of the test support enclosure and the test chamber walking surface above the floor wedges.

Instrumentation System. The National Instruments Sound Power System (SPS) automates the process of noise emission testing in free-field test environments. It incorporates PC-based instruments with LabVIEW™ based software to provide sound power and sound pressure measurements. Because it is a PC-based, the system has a higher performance and less opportunity for error than comparable systems. The system implements acoustic measurement procedures defined in ANSI S12.34-1988, ANSI S12.35-1990, ISO 7779 and EMCA-74 as well as a number of user-configurable options for other basic sound power and sound pressure level measurement standards, such as ISO 3744 and ISO 3745.

The SPS software is a ready-to-run application yet offers flexibility in functionality. The software was created with LabVIEW, a graphical programming environment for instrumentation. The source code can easily be changed for small adjustments or to provide additional functionality. The hardware consists of one or more National Instruments PC-based dynamic signal analyzers, a PC, microphones and optional multiplexers. Two noted domain specialists, David Nelson of Nelson Acoustical Engineering and Jeff G. Schmitt of JGS Consulting were employed to ensure compliance with the supported standards as well as ease of use.

Several configuration and calibration settings are available with the software. Configuration routines are menu-based, providing a step-by-step procedure for setting up the dynamic signal analyzer, the system of microphones and the microphone multiplexers. Configuration of the sound power and sound pressure level measurements provide settings for the number of positions to be measured, measurement times, as well as ambient and environmental corrections. Calibration is automated by a routine giving audio feedback that allows a single technician to cover multiple microphones. These calibration parameters are tracked in the software and give the user information on out-of-range conditions before they can affect the measurement data. Input forms are provided for test information, source documentation and recording of meteorological conditions.

Sound power and sound pressure level measurements are the core of the Sound Power System. The automated routine acquires data and performs real-time 1/3 octave band, A-weighted, and linear levels over a user-selectable frequency range of 25 Hz to 20 kHz. The sound pressure level routine includes sound quality analysis for impulsive noise and prominent tones. A 12,800 line FFT is used to perform prominent tone analysis by both the tone-to-noise and prominence ratio methods.

Test reports and documentation are generated automatically using Microsoft Excel. The Sound Power System generates a certificate-style report template. The data are exported to a Microsoft Excel spreadsheet and can be customized using Excel or other Microsoft Office tools.

Customized Test Software. Testing of space-flight hardware presents two practical challenges. First, ISS noise emission criteria require that all likely operational states be tested. Second, portable support equipment serving the hardware under test often lacks the capacity of its on-orbit counterparts, limiting the duration of test. On both counts, simultaneous multi-channel data acquisition is a practical necessity.

To support this requirement, Nelson Acoustical Engineering developed the "Multi-Channel Enhancement" (MCE) software that augments the functionality of National Instruments' Sound Power System. By grafting onto the SPS source code, the MCE was tailored to NASA's needs without reinventing SPS's comprehensive configuration, calibration, computation and documentation functions.

The MCE's dual display gives results both for an individual user-selectable measurement position and for all positions simultaneously (see Figures 9 and 10). Missing or overloaded channels are plainly identifiable. Display options include one-third octave band levels, octave band levels, an NC-40 reference curve for comparison to the ISS rack criterion, stored or live data, and per-channel overload indicators. Acquired data are written back to SPS for computation, documentation and export.

The MCE has been designed for future expansion. The number of simultaneous measurement channels is limited only by the number of dynamic signal acquisition (DSA) boards in the system.

Figure 11. This fan, typical of space experiment payload noise sources, provides ventilation for a rack that houses a number of experiments.

Summary. NASA has designed and constructed a convertible hemi-anechoic Acoustical Testing Laboratory that provides convenient access to accurate and repeatable sound pressure level measurements as well as state-of-the art capabilities for sound power level testing per ANSI S12.35. The Glenn Research Center Acoustical Testing Laboratory provides testing services for microgravity space flight hardware that will reside on the International Space Station as well as for commercial products and other non-NASA hardware (see Figure 11). The Laboratory intends to earn accreditation by the National Voluntary Laboratory Accreditation Program (NVLAP) by this time next year, which will rank the ATL with a small number of accredited acoustical testing laboratories nationwide.

1. Pressurized Payloads Interface Requirements Document, International Space Station, National Aeronautics and Space Administration, SSP 57000 Revision E, April 21, 2000.
2. American National Standard Engineering Methods for the Determination of Sound Power Levels of Noise Sources for Essentially Free-Field Conditions over a Reflecting Plane, ANSI S12.34-1988 (R1997).
3. American National Standard Precision Methods for the Determination of Sound Power Levels of Noise Sources in Anechoic and Hemi-Anechoic Rooms, ANSI S12.35-1990 (R1996).

Cover: The NASA Glenn Research Center Acoustical Testing Laboratory is a 100 Hz. vibration-isolated anechoic chamber with 27-ft by 23-ft by 20-ft (high) outside dimensions and removable floor wedges that allow the facility to be configured as either a hemianechoic or fully-anechoic chamber. A separate, sound-isolated control room doubles as a test support equipment enclosure when testing articles that require remote connections to high-noise support equipment and services. Movable modular furnishings facilitate reconfiguration of the enclosure so that data acquisition and test control functions may be easily relocated to an adjacent quiet area. As an in-house laboratory, the ATL provides an accessible, secure and flight-hardware-compatible acoustical testing environment to support the low-noise design of microgravity space flight hardware that must meet International Space Station limits on noise emissions. The ATL provides acoustic emissions testing and noise control services to help meet ISS hearing conservation and speech communication goals. *(Photo courtesy of NASA John H. Glenn Research Center at Lewis Field, Cleveland, OH)*